AD-A016 861

RUPTURE AS A FUNCTION OF DEFORMATION IN FLAT PLATES
EXPOSED TO HE MINE BLAST

Richard M. Norman
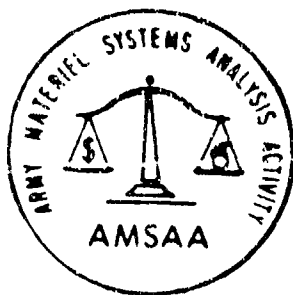
Army Materiel Systems Analysis Activity
Aberdeen Proving Ground, Maryland

May 1975

316114

AD

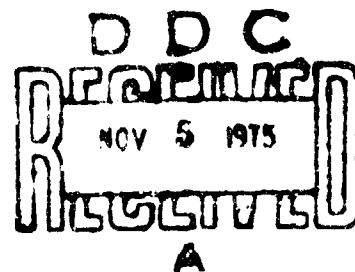# AMSAA

TECHNICAL REPORT NO. 127

RUPTURE AS A FUNCTION OF DEFORMATION IN FLAT PLATES
EXPOSED TO HE MINE BLAST

RICHARD M. NORMAN

MAY 1975

D D C

NOV 5 1975

A

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

ADA016861

U.S. ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY
Aberdeen Proving Ground, Maryland

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AMSAA Technical Report No. 127	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Rupture as a Function of Deformation in Flat Plates Exposed to HE Mine Blast		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Richard M. Norman		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Materiel Systems Analysis Activity Aberdeen Proving Ground, Maryland 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DA Project No. 1T765706M541
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Materiel Command 5001 Eisenhower Avenue Alexandria, Virginia 22333		12. REPORT DATE May 1975
		13. NUMBER OF PAGES 17
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

plate deformation   armored vehicles
plate rupture   armor vulnerability
antitank mines   crew injury

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report addresses the vulnerability of armored vehicles and possible injury of their occupants to HE mine blast loading. Specifically reported are the results of literary research in the following two areas:

    a. The value (height) of flat plate deformation that can be associated with plate rupture.

DD FORM 1473 1 JAN 73   EDITION OF 1 NOV 65 IS OBSOLETE

b. the hazard to vehicle occupants of the vertical motion of the floor armor, especially the elastic (temporary) deflection.

Values are shown for the threshold of plate rupture as a function of deformation for various plate thicknesses. Vertical, elastic-phase, deflections of one or two inches for large, open, floor areas are predicted, for non-rupturing blast mine loading. Occupant injuries are likely here, and shock isolation references are briefly discussed.

This is a follow-on report to AMSAA TM-74 (Reference 1), an estimate of deformation as a function of HE mine charge weight.

CONTENTS

RUPTURE AS A FUNCTION OF DEFORMATION IN
FLAT PLATES EXPOSED TO HE MINE BLAST

1. INTRODUCTION

1.1 Purpose.

This report addresses the vulnerability of armored vehicles to
HE mine blast. Specifically, it is an attempt to estimate the
amount of floor plate deformation at which plate rupture occurs. This
information has potential value in the following subject areas:

a. Predicting the type and extent of damage a blast mine can
inflict on a given type vehicle.

b. Providing gross plate-response and rupture-data points
for modelers of plate response.

c. Predicting the amount of vertical acceleration received
by vehicle occupants adjacent to the plate.

Also, the inter-relationship of plate response and occupant injury
is briefly addressed.

1.2 Background.

This is a follow-on report to AMSAA TM-74 (Ref. 1*). In that
report test data from mine-vs-plate firings were used to estimate plate
deformation as a function of HE charge weight. The effort herein is a
re-use of that data, this time to fit curves of the probability of plate
rupture to the values of plate deformation. The original sources of
these data are References 2 and 3, test reports of firings of HE charges
against flat plates.

1.3 Plate Response Modelling.

The applicability of computerized plate response models to the
mine-vs-plate subject area has been briefly looked into by the
Ballistics Research Laboratories (BRL). A pilot run of an existing
finite-difference program was made, and this is described in Reference
4. The run was successful in that a deflection-versus-time history of
the deforming event was obtained. The practicality of the results is
limited only by the type of assumptions that had to be made in several
input data areas. One critical area involved the ultimate failure
values for armor materials under dynamic loading.

Since that time, improved response models have been developed,
such as described in Reference 5. However, until the input situation
is improved, the information to be developed in this text may have
potential use as an empirical complement to the plate response model
output. That is, the probability of plate rupture, presented as a

---

* References may be found on page 17.

function of deformation, could be combined with the deformation-versus-time output of the models to more completely describe the blast mine effect.

2. ESTIMATING THE RUPTURE-VS-DEFORMATION THRESHOLD

2.1 The Data.

Basically, the tests were simulations of the detonation of an antitank mine under an armored vehicle. A 5 x 7 foot sheet of armor plate was horizontally positioned on supporting blocks so that its center was approximately 17 inches above the top of a buried HE charge. The charge was loosely covered with up to three inches of soil. A heavy picture-frame-like weight with an interior opening of approximately 40 by 64 inches was then placed on the test plate. Firing the charge deformed the test plate upwards into the frame opening and often cracked or broke the plate. The final height of the central bulge of the deformed plate and the descriptions and dimensions of the cracking form the bulk of the post-firing data of the references.

This report will focus on only two aspects of those test results, i.e., the final deformation (in inches), and the success or failure of the charge to cause a crack of six inches (arbitrary) or longer in the plate. These results, with success or failure scored as 1 or 0, respectively, are shown in Table I.

The material of these plates was either steel armor plate, 'MIL-S-12560, Class I, or aluminum alloy armor plate, 5083-H322. It is unfortunate for this investigation that Class I, rather than Class II, steel plate was involved. Class II is the steel currently recommended for belly armor of vehicles exposed to a blast antitank mine threat, and the testing reported in the references occurred prior to addition of Class II to the specification. Information equivalent to that of the references for Class II could not be found.

All of the steel plate testing reported was performed in the ambient temperature existing at the time, and all plates had a crack-starter. This is a small block welded to the center of the upper side of the plate to simulate the typical attachment of an internal vehicle component to the plate. Some of the aluminum alloy plate firings were performed at a special temperature of -40°F, rather than ambient, and some were without crack-starter. These conditions are noted in Table I.

2.2 The Graphical Analysis.

The plate deformation and one-or-zero information for steel plate was plotted into the seven small probability graphs shown as sub-elements of Figure 1. Each small graph is vertically centered at the appropriate plate thickness value on the ordinate of the large graph.

TABLE 1. PLATE DEFORMATION D_F AND RUPTURE* INFORMATION FOR HE CHARGES
VERSUS FLAT PLATES

Steel Plates

D_F (ins)	Rup-ture	D_F (ins)	Rup-ture	D_F (ins)	Rup-ture
1/4 in.					
.88	0	9.25	0	12.00	1
1.25	0	9.63	0	13.00	1
3.00	0	10.50	1	14.25	1
4.00	1	11.50	1	1 1/4 in.	
4.38	1	13.63	1	7.00	0
4.50	1	14.00	1	7.63	0
10.63	1	3/4 in.		7.75	0
3/8 in.		2.88	0	8.00	1
2.75	0	4.25	0	8.25	0
3.00	0	4.50	0	8.50	1
3.00	0	6.00	0	1 1/2 in.	
3.13	0	6.00	0	6.50	0
3.25	0	6.50	1	6.63	0
3.75	0	6.63	0	7.50	0
4.25	1	9.38	1	8.50	1
4.75	1	10.00	1	8.75	1
5.50	1	11.50	1		
8.25	1	14.13	1		
8.50	1	15.63	1		
13.75	1	1 in.			
1/2 in.		6.50	0		
0.00	0	6.63	0		
4.50	0	8.00	1		
5.75	0	8.00	1		
6.75	1	8.25	0		
9.00	0	8.63	1		
		10.13	1		
		10.88	1		

Aluminum Plates

D_F (ins)	Rup-ture	Note**	D_F (ins)	Rup-ture	Note
3/4 in.			2 in.		
6.00	0		8.50	0	
11.25	0	W/O	13.25	0	W/O
10.25	0	W/O	13.50	1	W/O
11.50	0		14.50	1	
21.00	1		22.50	1	
9.75	0	-40	9.25	1	-40
11.00	0	-40	2 1/2 in.		
1 1/4 in.			9.75	0	
7.75	0	W/O	11.75	0	W/O
10.00	0	W/O	10.00	1	W/O
9.25	0		10.50	0	
10.75	1		21.00	1	
19.50	1		10.00	0	-40
9.50	0	-40	15.00	1	-40
1 3/4 in.			3 in.		
6.88	0	W/O	8.50	0	W/O
12.00	0	W/O	10.75	0	W/O
11.00	0		7.00	0	
12.00	0		17.00	1	
9.00	0	-40	25.00	1	-40
9.00	0	-40	12.00	1	-40
10.50	0	-40	17.50	1	-40

* Plate Rupture, YES or NO, is denoted by 1 or 0 respectively. Fractions shown are the plate thicknesses.

** Unless noted otherwise, all steel and aluminum plates had a crack-starter and were tested at ambient temperature. Where noted, W/O means without crack-starter, and -40 means plates were tested at -40 F.
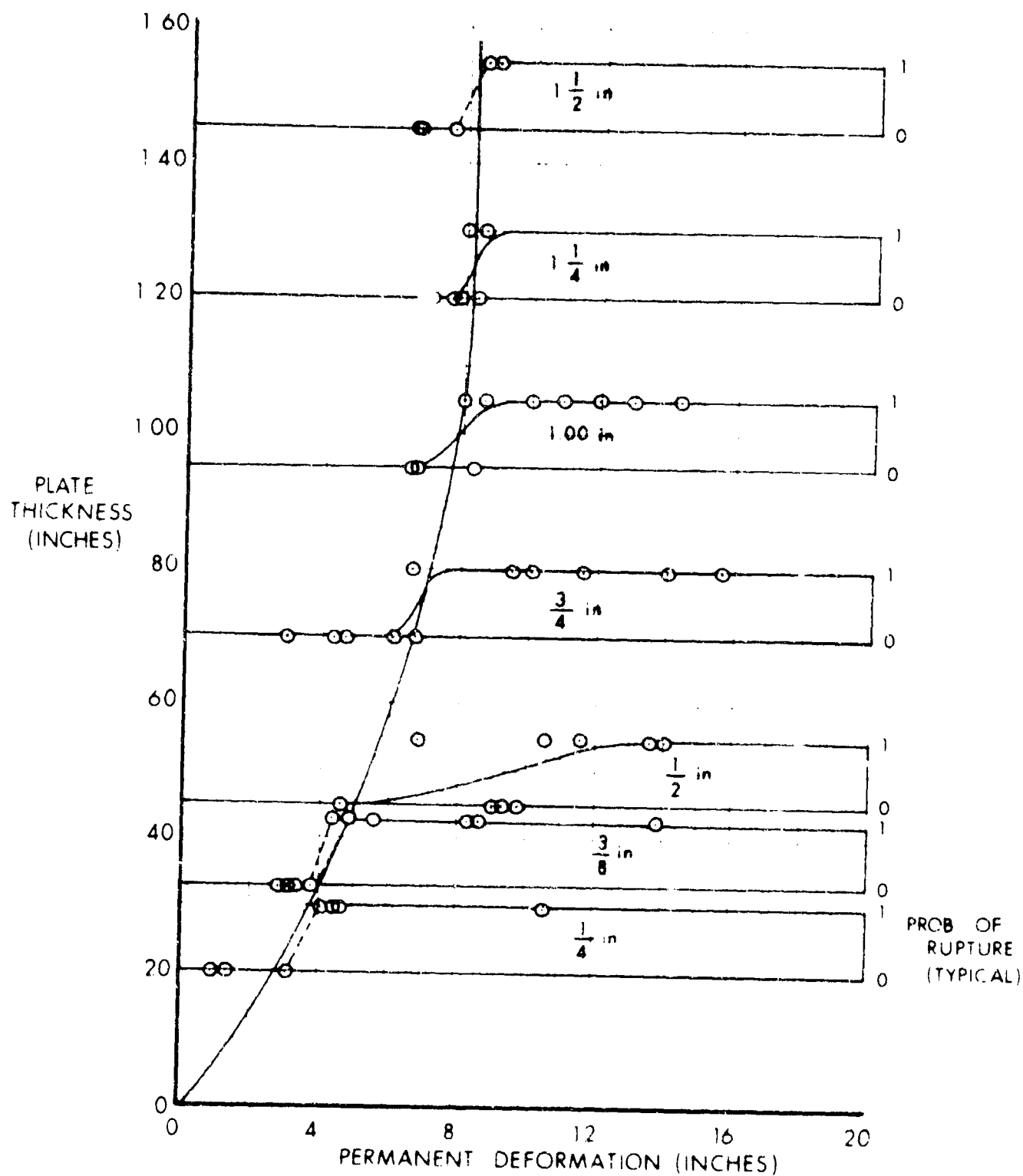
Figure 1   An Investigation of the Threshold of Plate Rupture
for Steel RHA as a Function of Deformation (Circles
are Data Points, Small Curves are Estimated Mean
Values of Deformation)

Thus visual transfer of information from one small graph to another is in proportion to plate thickness.

The next step was to draw curves having the maximum likelihood of fitting the data in the transitional intervals; i.e., the interval of deformation values in which the probability of plate rupture goes from 0, through .5, to 1.0. To assist in this, an existing FORTRAN computer sub-routine* was selected. This program computes the mean and standard deviation of the cumulative normal curve that best fits the data. It does require, however, that the data contain a region of mixed results, i.e., at least one failure to rupture must have occurred at a deformation value larger than the lowest deformation value that yielded a success.

Computer runs were made, using the input data of Table I. For the four sets of plate data that contained regions of mixed results, the following means and deviations were obtained:

Plate Thickness (in)	Mean Deformation (in)	Standard Deviation (in)
1/2	9.35	2.82
3/4	6.62	0.37
1	7.80	0.70
1 1/4	8.15	0.34

Small cumulative normal curves conforming to these values were drawn into Figure 1, as the curves shown in solid line. In the plate thicknesses where the deformation-rupture data did not contain regions of mixed results, straight lines were visually fitted to the transitional interval, as shown in dashed line.

After the probability curves for each small graph were completed, the large curve was visually fitted through the .5 probability value of each small curve. Thus the large graph is now a rough estimate of the position of the rupture threshold for other intermediate thicknesses of this material having the same length and width and loaded in the same manner.

No explanation for the comparatively wide spread in results for the 1/2-inch plate can be given from the data at hand. This plate thicknesses was ignored in the visual fit of the large curve of Figure 1 to the small graphs.

---

* This sub-routine was written by Mr. Richard Peterson, of AMSAA, and is based on methodology derived from Reference 6.

The graphical process described above for steel was attempted also for the aluminum alloy armor data of Table I. This is shown in Figure 2. The irregularity of the data in the small graphs precluded the drawing of the large curve, however, there does seem to be a tendency in all the thicknesses shown for plate rupture at about 10 to 14 inches of deformation.

5. DISCUSSION

3.1 Vehicle Vulnerability.

The rupture-deformation relationship could provide guidance to armored vehicle design. For example, consider a conceptual vehicle having one-inch thick steel belly armor. An open expanse of the bottom of roughly the same area as the test plates could be deformed up to six inches or so and yet not rupture. If, however, the deformed plate interfered with a critical vehicle control or component, the fact that the hull had not ruptured would be academic. Therefore, it would seem appropriate to insure, where possible, that all critical items are spaced above the vehicles bottom armor by a distance at least equal to the rupture threshold of that armor. The information of Figures 1 and 2 could be used as a rough estimate of the threshold distance, within the limitations pointed out in Section 2. Also, the deformation-rupture data could be used in assessing the vulnerability of existing vehicles.

3.2 Occupant Injury.

In Reference 1 the probability of occupant injury for blast mine attacks of armored vehicles was briefly discussed. Although a mine may not always succeed in rupturing the vehicle bottom armor, the sudden upward displacement of the armor in the deformed area may injure nearby occupants. "Later", in milliseconds, gross vehicle upward motion or overturning is a further source of injury. This section will address the events local to the deformed area, and more specifically, will introduce a consideration not treated in Reference 1, that is, the temporary upward deflection existing only during the actual stress.

3.2.1 The Temporary Deflection.

In the estimates of injury made in the previous report, the plate final deformation was used as the best estimate of the initial upward displacement to which an occupant would be exposed. This would be in error, of course, if a large proportion of the plate deflection is elastic, i.e., existing only during (approximately) peak plate stress and subsiding to the final permanent deformation after loading. This temporary deflection has recently been investigated and reported as one of the experiments described in Reference 7. Data from that report form the empirical base for this discussion.
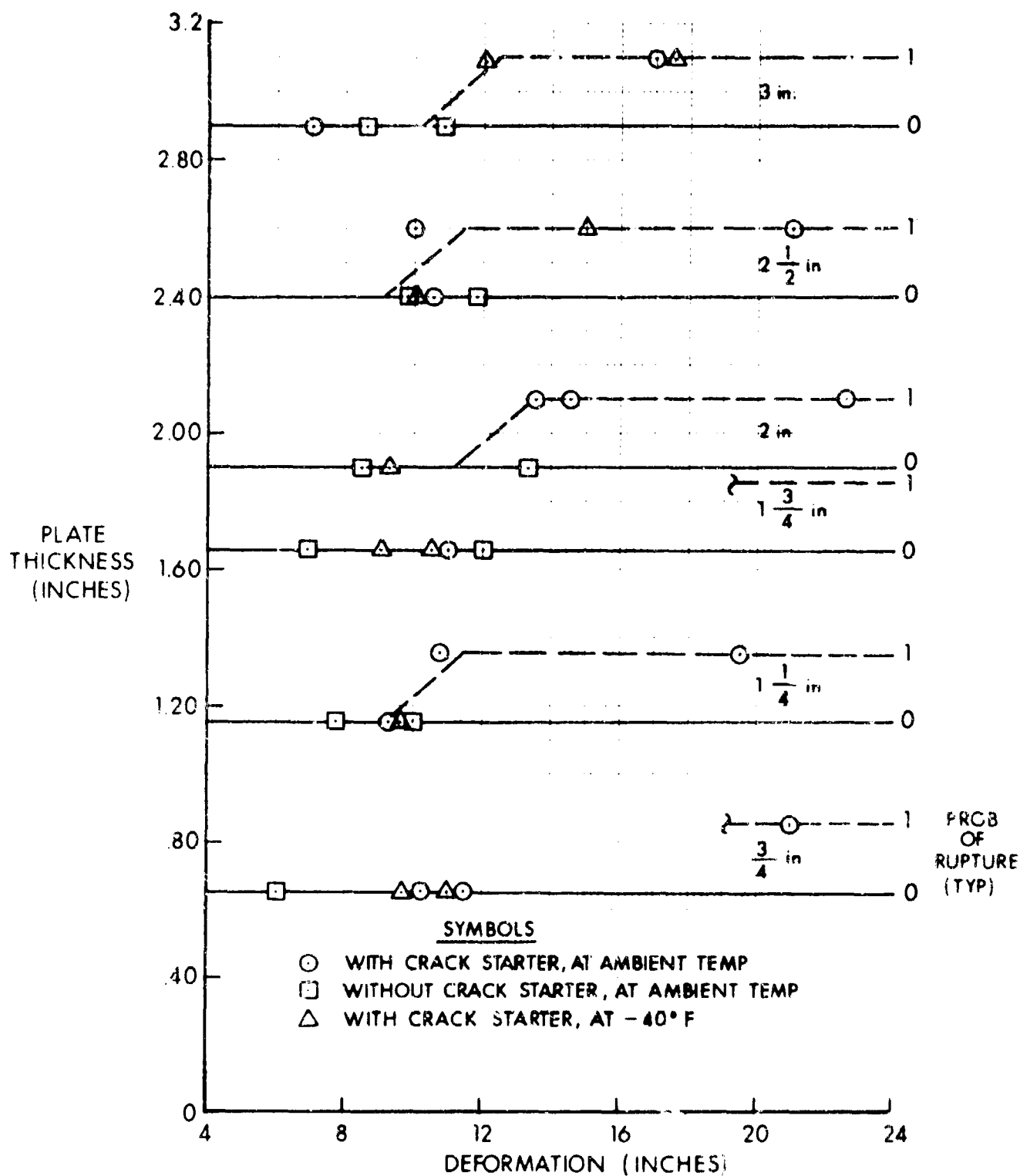
Figure 2. Plate Rupture -vs- Deformation for Alum. Alloy Plates (Dashed Lines are Estimates of the Rupture Threshold.)

The effort reported involved both one-fourth and one-half scale firings of HE charges versus flat plates. Both series of scaled tests were attempts to model the behavior of one-inch steel armor in the test configuration described in Section 2.1 herein. The techniques used to scale the explosive weight and distances are described in the reference. Experiments representing two different vehicle ground-clearances , 14 and 24 inches , were performed. Both the maximum height of temporary deflection (D_T) and the final deformation (D_F) were measured. Table II shows the data, from the one-half scale effort, for the two ground clearances. Both D_T and D_F have already been multiplied by approximately two. (If the plate thickness of the model deviated from the nominal one-half inch value, the factor used to up-scale the data was adjusted from two to the correct value.)

Figure 3 shows ΔD , the elastic deflection, in more detail. ($\Delta D = D_T - D_F$) It shows that D_F can be an underestimate of D_T by approximately one or two inches for the specific conditions described in the reference . In more severely loaded plates, where final deformation is approaching the rupture threshold (approximately eight inches, see Figure 1) then D_F and D_T are within an inch.

3.2.2 Upward Velocity

The observations of Section 3.2.1 suggest that zero or small permanent deformations do not necessarily imply zero or low chances of occupant injury. During the vertical displacement associated with the elastic phase of material response high velocities would seem likely. Consider, for example, an elastic deflection of two inches (.17 feet) with a time-to-peak-deflection of one millisecond. (Reference 7 estimates times of .5 to 1.5 ms. for this.) The average velocity through this displacement is 170 fps (i.e., from .17 ft/1 ms). Assuming, for convenience, a triangular velocity-time profile, the peak velocity would be twice the average velocity or more, or at least 340 fps. , and would occur at approximately .5 ms. This velocity would be easily injurious to a vehicle occupant exposed to it, as shown , for example, in Reference 8, Figures 7 and 8. This elastic phase of plate motion may be the deck-slap injury mechanism of Reference 9, a reference discussed in Reference 8.

4. SUMMARY AND RECOMMENDATIONS

A basic relationship of rupture to deformation has been shown in steel plates subjected to HE mine attack, as shown in Figure 1.

TABLE II. PLATE DEFORMATION INFORMATION* FOR HE CHARGES-VS-ONE INCH STEEL PLATES
(FROM THE ONE-HALF SCALE EXPERIMENTS OF REFERENCE 7)

	Height, Plate-to-ground = 14 ins.				Height, Plate-to-ground = 24 ins.		
Test No.	D_F (ins)	D_T (ins)	ΔD (ins)	Test No.	D_F (ins)	D_T (ins)	ΔD (ins)
32	1.09	2.30	1.21		—	—	
33	1.08	1.21	.13				
Aver.	1.09	1.75	.67				
31	2.46	4.63	2.17		—	—	
41	1.58	3.55	1.97				
Aver.	2.02	4.09	2.07				
20	4.25	5.40	1.15	26	1.47	3.32	1.85
27	3.53	4.66	1.13				
Aver	3.89	5.03	1.14				
18	7.21	7.91	.70	22	4.29	5.61	1.32
25	7.14	8.16	1.02	24	4.27	5.69	1.42
28	6.76	7.54	.78				
Aver.	7.04	7.87	.83	Aver.	4.28	5.65	1.37
	---			40	7.68	8.32	.64
				44	11.06	11.81	.75
				Aver.	9.37	10.07	.70

* D_T is Maximum Height of Temporary Plate Deflection. D_F is Final Deformation.

$\Delta D = D_T - D_F$. A three-inch charge burial depth was simulated. Data is grouped by like charge weight.
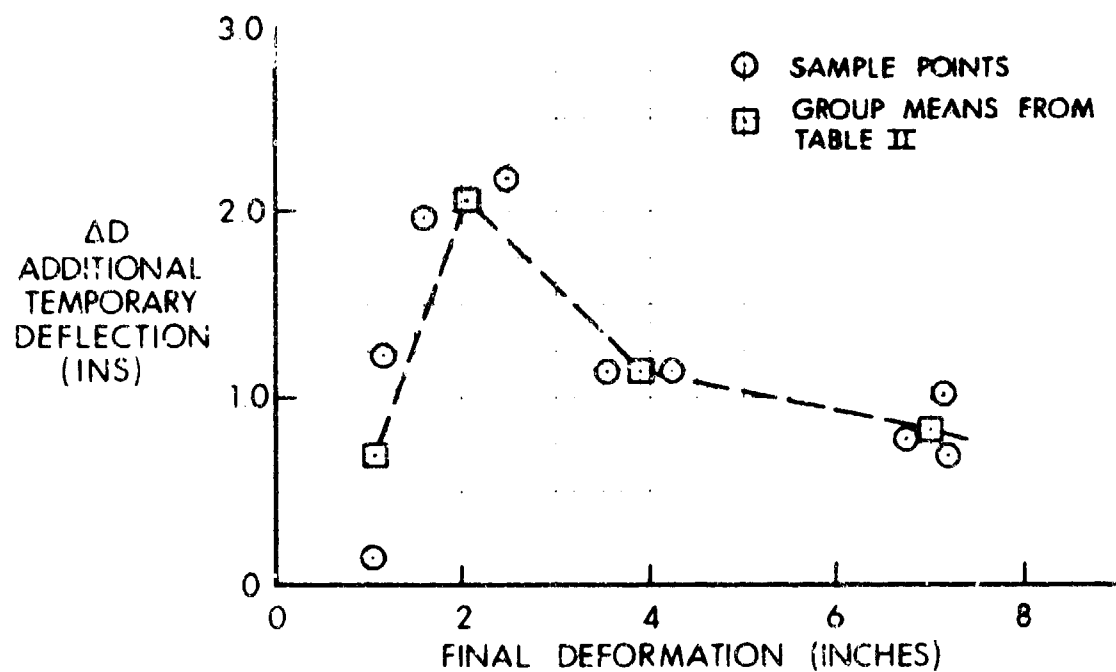
13

Figure 3. Additional Temporary Deflection vs Final Deformation for the 1/2 Scale Firing Data.

The value of deformation at the threshold of plate rupture is suggested as a guide to the placement of critical vehicle controls or components. Further, the rupture-versus-deformation threshold can be potentially useful as a complement to the output of plate-response computer programs.

Based on scaled test data from Reference 7, the elastic (i.e., temporary) portion of plate upward motion has been roughly quantified. Temporary vertical deflections of one to two inches could occur in addition to the associated permanent deformation in non-rupturing plate loading. Injury to vehicle occupants adjacent to the plate is likely, from both the elastic and the permanent deflection.

It is recommended that new armored vehicle designs consider as much isolation from these high accelerations as practical. Past efforts in this have included crushable support columns for seats, crushable (not elastic) mats for floors, special design of footrests, and suspension of crew seats from overhead. Typical approaches in these areas are discussed in Reference 10, 11, and 12. The continuous review and update of such effort by the armored vehicle design or testing community would seem warranted.

REFERENCES

1. Norman, Richard M., Deformation in Flat Plates Exposed to HE Mine Blast (U), Army Materiel Systems Analysis Agency, Aberdeen Proving Ground, MD 21005. AMSAA TM-74, May 1970 (CONFIDENTIAL) (AD 511-758)

2. Carson, D.C., Armor Protection Against Land Mines (U), Development and Proof Services (now Materiel Test Directorate), Aberdeen Proving Ground, MD 21005. DPS/TT1-5/56, March 1957 (CONFIDENTIAL) (AD 143-153)

3. Resnick, W.V., Investigation of the Resistance of Aluminum Armor Plate of Various Thickness to AT Mine Attack at Ambient and Sub-Zero Temperatures (U), Development and Proof Services (now Materiel Test Directorate), Aberdeen Proving Ground, MD 21005. DPS/TB4-005/3, February 1960 (CONFIDENTIAL) (AD 315-462)

4. Huffington, Norris J., Jr., Blast Response of Panels, US Army Ballistic Research Laboratories, Aberdeen Proving Ground, MD 21005. BRL TN 1702 (UNCLASSIFIED)

5. Santiago, J.M., et al, A User's Manual for the REPSIL Code, US Army Ballistic Research Laboratories, Aberdeen Proving Ground, MD 21005. BRL Report R 1744 (UNCLASSIFIED)

6. Grubbs, Frank E. and Golub, Abraham, Analysis of Sensitivity Experiments When the Levels of Stimulus Cannot be Controlled, Journal of the American Statistical Association, June 1956 (pages 257-265) (Also published as BRL TN 151, 1956)

7. Wenzel, Alex B., and Esparza, Edward D, The Response of Armor Plates to Land Mines, Using Model Experiments (U) Southwest Research Institute, for US Army Tank-Automotive Command. TACOM Technical Report No. 11848, March 1974 (CONFIDENTIAL)

8. Hirsch, Arthur E., Man's Response to Shock Motions, US Naval Ship Research and Development Center, Carderock, MD. Report No. 1797, January 1964 (UNCLASSIFIED) (AD 436-809)

9. Barr, J.S., et al, Solid Blast Personnel Injury: A Clinical Study from the Military Surgeon, Vol. 98, No. 1, March 1945 (UNCLASSIFIED)

10. Strother, Charles E., An Exploratory Investigation of the Threat to Armored Vehicle Personnel from Mine-Induced Shock Motion (U) US Naval Ship Research and Development Center, Washington, DC 20007. Report No. C-2711, April 1968 (CONFIDENTIAL) (AD 391-405)

11. Frye, W.B., _Product Improvement Test of Carrier, M113A1 (Ballistic Test, Sponson Reinforcement Kit) (U)_, Aberdeen Proving Ground Firing Record No. Ar-30664, January 1972   (CONFIDENTIAL)

12. Frye, W.B., _Engineer Design Test of Armor, Steel Applique to Investigate G Forces Loading Under Mine Attack for ARSV_, Aberdeen Firing Record No. Ar-30912, March 1972   (UNCLASSIFIED)